$C_2 = 0.032$ for 6-foot pans.
$C_2 = 0.037$ for 4-foot pans.
$C_2 = 0.042$ for 2-foot pans.

These coefficients may be increased for the plateau or elevated stations.

It is not yet clear how we can obtain the corresponding coefficient over very large water surfaces, owing to the difficulty of measuring the rain, the inflow and outflow, and changes other than those due to the simple evaporation. There is an apparent small defect in the coefficient in the forenoon hours and excess in the afternoon hours by all formulas, and this may be connected with the interplay of the specific and latent heats during the warming of the water temperature in the forenoon and cooling in the afternoon hours. It is this class of questions that always render any research into evaporation very difficult, and while a laboratory may be needed to settle certain points, it is not seen how the confined conditions of a laboratory can be made to become a safe substitute for the natural laboratory in the open air.

VI.—ON CERTAIN MINOR PROBLEMS IN EVAPORATION.

The major problems in evaporation consist in securing the proper form of the formula and the coefficients or constants. We have found that the coefficient of diffusion varies with the size of the pan, due to the banking up of the vapor on the leeward side under the action of the wind. A small pan clears much more completely of vapor than a large pan, so that the evaporation takes place into a mixture of air of different contents according to the size of the pan and the force of the wind. Having made numerous readings on pans whose diameters are 2 feet, 3 feet, 4 feet, 6 feet, respectively, it becomes evident that the C-coefficient decreases as the size of the pan increases, something like $C=0.042$ for a 2-foot pan to $C=0.031$ for a 6-foot pan. The question how to exturpolate the series to a large lake or water surface is practically very difficult. This unexpected problem has arisen in our research of 1909, and it will require a special series of observations in 1910 to settle it.

A brief experience with the computations of the data of evaporation by means of formulas containing the terms (e_s-e_d) Dalton, (e_t-e_d) Mammoth, $(e_s+e_t-2e_d)$ Marvin, convinces us that the theory upon which they depend, namely, that the evaporation is proportional to the *difference* of such vapor pressures as a potential is really insufficient. These formulas imply that the evaporation ceases when these terms become zero, as is the case in saturation when $e_s=e_t=e_d$. This theory proceeds on the assumption that *saturation* of the air implies *stagnation* of the vapor, which is obviously not true. There is usually a visible movement of circulation upward in a cumulus cloud; there is rapid movement of air through a saturated cloud cap or tablecloth on a mountain, which contradicts the idea. Suppose a vapor blanket overlies a body of water, saturated as fog or visible vapor in the lowest layers, it yet soon reaches an unsaturated state at some distance above it vertically. There is probably a continuous movement of vapor upward through this vapor blanket from the saturated surface layers to the unsaturated upper layers. This can only take place when the water continues to evaporate into the fog, while the fog circulates upward to supply the losses on the upper layers caused by the wind action or by the simple diffusion into the unsaturated layers. In this case saturation is accompanied by circulation and not stagnation, such as is implied in the Dalton, Mammoth, and Marvin formulas, at their limit. The question when evaporation ceases is a complex one, and the further question, why the C-coefficients show such irregularities in apparently the same conditions of temperature, vapor pressure, and wind, in both dry and humid regions, during strong evaporation, demands a full investigation. These points are illustrated in any collection of C-coefficients given in our tables, and they can not be ascribed to the observations so far as their superficial accuracy is concerned. They undoubtedly depend upon certain subtle molecular processes which are only inadequately recorded in the usual meteorological data. These questions are of such interest and novelty that I am happy to quote Mr. W. F. Lehman's preliminary report on these topics and commend his attack upon the problems.

REPORT ON EVAPORATION AT BIRMINGHAM, ALA., 1909.

W. F. LEHMAN, Observer, Birmingham, Ala.

My principal object in making the tests was not so much to study absolute evaporation values as to ascertain how long evaporation would go on in an atmosphere charged with moisture to near saturation, and to discover, if possible, the causes of the discrepancies in evaporation measurements observed under similar weather conditions. That the differences were due more to the activity, not the amount, of the water vapor in the air than to any other of the meteorological elements considered as factors in the evaporation formulas, I concluded from our experiments made in 1908 at the Shades Mountain Reservoir of the Birmingham Water Works Company. During the dry summer months of 1908 we obtained by means of the Trabert formula constants that were constant to a certain degree. But during the following winter season our enthusiasm was dampened considerably. Evaporation was observed to be large where we expected little, and little water evaporated where we expected larger amounts. But one fact was also soon noted, namely, the most divergent results were obtained on days when a cyclonic area was expected to pass over this section within 36 hours. Though the moisture conditions did not differ much at the reservoir on such days, they differed materially in the dry district where the Weather Bureau is located.

I am hopeful that the special tests, which I understand are to be carried on at several stations east of the Mississippi, will confirm the observations enumerated in the following. All observations were made during rainy weather or when rain was expected.

During the latter half of May the experiments were confined to observing evaporation from small water pans and from a Piche evaporometer. A thoroughly moistened sheet of letter paper placed in a pan was also exposed with the other apparatus in places sheltered from the rain, but accessible to the wind, and with the same temperature and humidity conditions as prevailed in the station instrument shelter. The results varied as much under practically the same conditions and were often alike under entirely different conditions as those obtained at East Lake in fair weather.

By the end of May the Tennessee Company had completed a whole year's record of evaporation at Shades Mountain, and the instruments and apparatus used in the experiments were put at my disposal for carrying on further investigations. The evaporation tank, 3 feet square and 1.5 foot deep, was sunk into the ground in the clear space between the Weather Bureau building and the instrument shelter. But before the tank was filled some comparative rainfall measurements were taken with the four gages on hand.

The method of placing a rain gage near the evaporation pan, or on shore while the pan floats in the lake, and of subtracting the amount of rainfall from the height of the water in the pan, is unreliable. I had placed three gages together in the bottom of the tank, and all three showed different amounts after a shower, the proportionately greatest differences showed after showers of short duration and amounting to from 0.05 to 0.15 inch.

About the middle of June the evaporation tank was filled and sheltered by a wooden, painted roof, which could easily be removed. The edges of the roof overlapped the edges of the tank sufficiently to prevent the rain from falling in the tank on days with light winds, but they could not prevent the rain from being blown in by the stronger winds. This difficulty has only partly been overcome by surrounding the tank with a wire screen. Under the roof, sheltered from rain and wind, the Piche evaporometer was suspended, and the pan with the moistened sheet of paper was kept floating in the tank.

Although numerous showers occurred during June and July, there was only one period of frequent rains and high humidity, namely, June 19 to 23. But the wind velocities on these days, with the exception of the 22d, were such as to make it impossible to keep the rain from being blown into the tank. On June 22, a cloudy day with a relative humidity of 90 to 95 per cent from the ground to the roof of the Weather Bureau building, light showers from 6 a. m. to 2 p. m. were followed by heavy rain between 2 and 3 p. m. At 7 a. m. 0.03 inch of evaporation had been measured in the tank, and the same amount evaporated between 7 a. m. and 4 p. m. The sheet of paper had been wetted at 7 a. m. and was dry at 4 p. m., except in some places where stray splashes of rain were clearly visible. The Piche evaporometer kept on evaporating as it did, more or less, during any shower.

On the night of August 6–7 a rainfall lasting 6 hours occurred. It began shortly before the p. m. observation was taken. The amount was 0.76 inch and was about evenly distributed over the different hours. At 6 a. m. of the 7th, 0.07 inch of evaporation was measured in the tank, or only 0.03 inch short of the amount of dryand rainless nights. The other days of August were practically dry, and during September, with the exception of a few days, the same conditions prevailed. On September 10 the forenoon was cloudy and rainy, without any evaporation. On the 15th, with light showers, evaporation went on unchecked. The storm of the 21st made accurate measurements impossible.

These experiments, being made in the summer months, reveal nothing that could not reasonably be expected. Abnormal humidity conditions were due either to local evaporation, when evaporation would go on from the apparatus also, or to moisture carried to the place of observation by the winds from adjacent territory visited by rain. In the latter case evaporation would be checked to some extent. I think we would be in a better position to explain the discrepancies found in the East Lake results if the winds had been investigated, with regard to their vapor contents, before they entered the field of observation. If the moisture is carried along by a fresh or higher wind, it may not influence evaporation much; but in light winds or calms moisture, coming from an outside source and penetrating the air to a considerable height, may settle downward and stop evaporation effectually. On the other hand the upward movement of water vapor in dry and calm air, or in light winds, is very decided at times and may be observed on the sudden rise of the dew point temperature at the beginning of a rain shower in the face of a dry wind.

On a fair afternoon, with southeast winds varying in velocity from 2 to 8 miles per hour, the lawn on the weather side of the instrument shelter was wetted thoroughly to a distance of 25 feet, and at the same time the psychrometer and anemometer were observed. As long as the wind was strong enough it carried the moisture evaporated from the wet lawn away under the instrument shelter without affecting the readings of the thermometers. But as soon as the anemometer cups slowed down, the wet thermometer rose, while the dry remained stationary; and this rising and falling of the wet thermometer kept on in perfect harmony with the movement of the anemometer cups.

It will be seen from this that our p. m. records of humidity on dry summer days will become pretty unreliable at times. While I delayed the sprinkling of the Weather Bureau grounds until after the p. m. observation, I could not well request my neighbors, living within half a mile, to do the same with their lawns. The removal of the instruments to the roof of the building would not remedy the defect, since humidity readings 10 and 40 feet above the ground were about the same under these conditions. Thus, in this case, diffusion, probably aided by convection, is a rather active agent in distributing atmospheric moisture.

Diffusion is said to be a slow process, and as a proof of this assertion is given the fact that evaporation is at a minimum from a water surface over which the air has been made as nearly motionless as it is possible to do, as in a glass tube of small diameter, or in a closed vessel. That evaporation is retarded in such a vessel is ascribed to the high intensity of the water vapor blanket supposed to lie close to the water surface. I have made the experiment with glass tubes of small diameter, firmly fixed to the wall, and days elapsed before any measurable amount of evaporation could be noticed. Owing to the small bore of the tubes, there was no way of finding out the activity of the vapor within. But on making the experiment with covered glass jars, of the Gordon battery, I could not find any dense vapor to within one millimeter from the water surface. The jars were put on chairs in a room which was closed, and left undisturbed for days in succession, and then was entered into for observation purposes only. On small cork disks, glazed at the top, pieces of writing and blotting paper were floated. These paper squares came to within one millimeter of the water surface, but they never attained any high degree of moisture. Removing the writing paper at intervals of from 2 to 15 days, some legend was written thereon as soon as the paper had been taken out, and in no case did the ink spread beyond the letters. I have even now some blotting paper floating in a jar for 40 days, and nearly a centimeter of water has evaporated from the water contents, still there is no sign of the paper ever becoming saturated. The evaporation shows that the moisture passing the paper must have been taken up by the latter, but the moisture as readily evaporated again. To prevent the air space in the jar from becoming saturated the jar was closed by a porous cover. If, in this case, there is a water vapor blanket over the surface, it must be less than a millimeter in height. I think it more probable that a water surface resists evaporation the same as it resists freezing and accomplishes this feat as long as it is perfectly at rest, and it is only when the surface is disturbed, by convectional currents, concussions, or the action of wind and sun, that evaporation really begins.

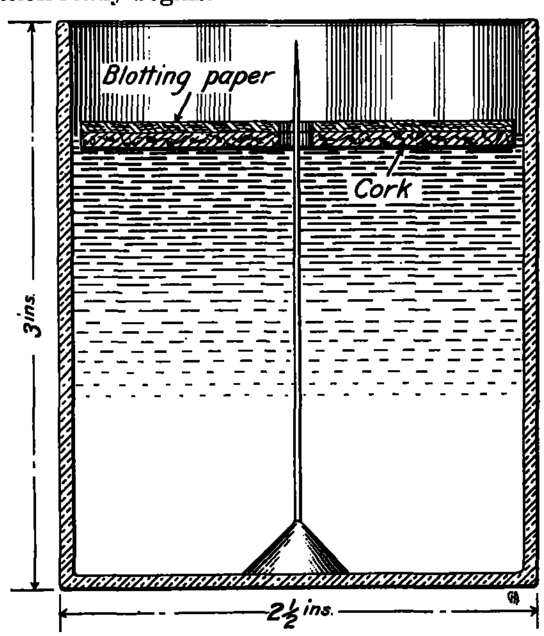

FIG. 1.—Floating disk evaporometer (Lehman).

Weather conditions more suitable for our purpose were looked for in the coming autumn and winter seasons, when rains in this section are generally caused by passing low pressure areas and are of longer duration than in summer, and when high humidities may prevail for days in succession. But to guard against loss of records during periods of high winds it was found necessary to construct a substitute for the Piche evaporometer, which latter instrument seldom showed evaporation in conformity to that of the other apparatus.

The evaporometer shown in fig. 1 is easily constructed and consists of a glass vessel 3 inches high and 2.5 inches in diameter. To the center of the bottom of the glass a pin is fixed, the point of which reaches up to within a few millimeters of the rim. The glass is filled with water, and a disk of thick blotting paper supported by a cork disk, both with holes in the center to admit the pin point, is floated on the top. The evaporation is measured to tenths of a millimeter by filling the glass by means of a burette tube until the pin point just dimples the water surface exposed at the center of the disk. Four of these instruments, all differing in height and diameter, were exposed under various conditions of weather together with the Piche evaporometer, and they always agreed in the amounts evaporated, but seldom harmonized with the latter instrument. The new evaporometer could not be exposed to fresh or stronger winds, but when mounted near the evaporation tank in light winds, the amounts evaporated from both apparatus were about alike. For the purpose of taking observations this instrument was either sheltered from the wind only, or from rain and wind, as occasion required.

The records obtained during October, November, and December have been tabulated but not inserted here because they are not strictly comparable, on account of the varying exposure the evaporation apparatus were subjected to. However, these records show clearly one fact, namely, that evaporation seldom ceases entirely at the places where the observations were taken, and this fact has been verified up to the date of this writing. The observations had to be discontinued on December 18, when the ice broke all the glass instruments. They were taken up again in the middle of January and since then have been made daily several times, not at fixed hours, but more with regard to weather conditions as prevailing during different periods. The evaporation tank is only covered during rainy weather, while the evaporometer is confined to the instrument shelter. Though quite unexpected results are still observed at times the amounts of evaporation recorded since October are generally in harmony with the conditions prevailing before, during, and after the passing of a cyclonic area over this section, whether or not the disturbance was causing any rain.

According to theory evaporation is furthered by the winds and is retarded in proportion to the decrease in the difference between the vapor tension at the surface temperature of the water and the vapor tension of the air above the water. If, as in the case of the evaporometer, the wind influence be eliminated and the temperature of the water in the instrument be made equal to that of the surrounding air, the amount of evaporation should be proportional to the psychrometric difference observed near the instrument. It will not take an observer in this section of the country any great length of time to find that the rate of evaporation, while usually, not always, high in dry weather, does not conform to the above theory during periods of high humidity. The actual degree of moisture may be high or low before the passing of a storm over this section, but the instances where humidity, absolute and relative, is low before the beginning of a rain attending a low are the rule rather than the exception. In 90 per cent of these cases all the rain falls before the storm center passes, and water vapor is supplied to the lower air by evaporation from the ground only. Under such conditions evaporation goes on unchecked from any apparatus. It is also noticed that the southeast wind rains are usually composed of large drops and are seldom of the misty type.

If, on the other hand, humidity increases with the approach of a low, evaporation is at a minimum from an exposed water pan, even though the relative humidity will not go above 80 per cent. If rains occur as long as the wind is southerly, they are light and misty, and sometimes stop evaporation entirely. The main showers in these cases occur with the arrival of the colder western portion of the storm area. If the low is not followed by any marked change to colder it may pass without causing any rain in this vicinity. The atmospheric humidity in these instances is usually identified with the moisture carried here by the southerly winds. But this theory is not supported by the fact that evaporation may be two or three times as large from an evaporometer in the instrument shelter, where the same relative humidity prevails as outside, than from an evaporometer or water pan not sheltered at the top and even exposed to the wind, nor by the fact that high humidity may prevail during a whole day and still evaporation be low during one part of the day and high during another. The south and southeast winds before and during a warm weather rain are as strong as the southerly winds preceding the rain caused by falling temperature in the rear of the storm center and blow over the same distance of dry territory. It is difficult to explain why they should be dry, sometimes even causing decreasing vapor tension by rising temperature in one case and increasing humidity in the other. It is more reasonable to assume that the dense clouds discharge some of their contents in the form of misty rain which evaporates before reaching the lower layers of the atmosphere, and this water vapor settles downward to the ground.

On November 1 we had every reason to expect rain, as the weather map of that day will show, but no rain occurred on the 1st or 2d. Relatively high humidity and dense cloudiness prevailed from 7 a. m. till noon of the 1st, and the evaporation measured at noon was 0.2 millimeter from the evaporometer exposed to precipitation, and amounted to the same in the water pan, also exposed. From noon to 4 p. m. the clouds became less dense, and patches of clear sky showed at times. The evaporation during this period was 1.2 and 1.0 millimeter from the evaporometer and pan, respectively. In the case of the pan the $e_s - e_d$ was 0.185 inch for the 5 forenoon hours and 0.255 inch for the 4 afternoon hours, and the difference between the forenoon and afternoon $e_s - e_d$ was 0.070 inch. But this little difference does not account for the much higher evaporation during the afternoon. The wind was south and decreased during the afternoon. The imperceptible precipitation had simply stopped after relieving the lower cloud layers of their surplus moisture.

The instances where relative humidities near 100 per cent were observed occurred, 1st, during a dense fog; 2d, near the end of several hours of misty rain; 3d, when the temperature fell away rapidly with the arrival of the cold winds in the rear of a storm center. In the latter case the water temperature in the evaporation apparatus remains several degrees above the air temperature, but this fact does not wholly explain the high evaporation recorded at such times. That evaporation sometimes goes on in the instrument shelter, with the same temperature and high humidity conditions as outside, and ceases from an exposed water surface, shows that water vapor circulates even when the air is nearly saturated. Dense fogs seldom occur in this section of the country, and since we know so little of the actual humidity conditions prevailing during a dense fog, the bulb of the dry thermometer being also wet, they should be studied closely with regard to evaporation and the other meteorological elements predominating before, during, and after the occurrence.

Evaporation and humidity have not yet attained any prominence as meteorological elements in preparing local forecasts of coming weather conditions, but I am satisfied that at the end of the present campaign it can be shown that these elements are not entirely interdependent of each other, and the theory that before a rain, attending the passing of a low, humidity increases and evaporation is at a minimum will have to be modified. If storms are nourished by moisture, little moisture they draw from the lower air layers of this section. The day before the storm of September 21 the vapor pressure steadily decreased and at 7 p. m. was lower than at any other time during the 17 days preceding the storm.

I have consulted humidity and evaporation conditions in preparing local forecasts since last October with generally good results, but I also met with failures. However, these failures were mostly due to miscalculations of the activity of the other meteorological elements. I intend to prepare a paper, illustrated by diagrams, on this subject.

The observations on evaporation should be made at all stations wherever practicable. Since they require much extra time, volunteers should be called for. But whenever made they should be taken by competent persons interested in the subject.

It will be seen from Mr. Lehman's observations that evidence has been secured to show that evaporation does not always cease during rain, fog, and heavy weather, that is during *intervals of saturation, but, on the contrary, there is positive* record that evaporation does continue. If this is confirmed by further experiment it tends to discredit the Dalton theory and its derivative formulas. I further quote from a report by A. B. Wollaber, United States Weather Bureau, Los Angeles, Cal. A Marvin self-registering apparatus has been set up to record the evaporation in fog and saturated air. The apparatus had been only recently installed, but the record of March 19 indicates four tips during fog.

The Marvin self-recording evaporometer is now in working order and giving very good results. We had some trouble with this instrument at first, due to some minor causes not easily detected by one not entirely familiar with it.

There are atmospheric conditions in Los Angeles that may prove a menace to accurate observations and I do not see how they can be overcome. A film forms over the water surface of the pan within a comparatively short time after exposure to the atmosphere caused by the great amount of dust in the air in this section. This is a different dust than that found on the desert and seems to be a combination of dust constantly stirred up from the streets and that due to the combustion of oil almost universally used for fuel in the buildings here. I did not think at first that this would amount to much, but after a few days the coating became sufficiently thick to hold up soot from the chimneys of adjacent buildings. I took particular notice of the conditions during a very dense fog that occurred on the 24th of February. Small globules of water formed on top of this film and some bubbles were also noticed. We discovered the difference between the bubbles and the drops by means of a pin, it being impossible to lift the latter on the point of the pin while the former burst when punctured. We were inclined at first to believe that the bubbles came from beneath the film, but closer examination showed that they were supported by it. I once thought to remove the instrument to my residence thinking that possibly we might overcome the difficulty in that way, but before doing so I put out a pan of water at my home and as the same filmy substance accumulated on the water there I abandoned the idea of removing the instrument. Inasmuch as the only desire is to secure these measurements during the prevalence of fog, I shall endeavor to devise some way of skimming off the surface whenever it becomes dirty. We cleaned the pan thoroughly on the 18th instant and on the 19th light fog prevailed from 5:30 to 11:15 a. m. *During this time the instrument recorded four times, showing an evaporation of 0.2 mm.* The instrument was working perfectly.

These facts have been presented to the readers of the MONTHLY WEATHER REVIEW, hoping that volunteers will be found, who can undertake observations of the sort indicated by these papers. It is very evident that as evaporation approaches its limit there are many conditions which it is not easy to observe and analyze, and yet they ought to be fully worked out in the interests of this important research.